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$K^*\Lambda(1116)$ photoproduction and nucleon resonances

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We study the reaction mechanism of $K^*\Lambda(1116)$ photoproduction off the proton target near threshold considering the contributions from nucleon-resonances. Employing the effective Lagrangian method at the tree-level Born approximation, we investigate the role of the $D_{13}(2080)$ and the $D_{15}(2200)$. We found that the D_{13} plays a crucial role to reproduce the experimental data well in the forward scattering region at low energy. We also present theoretical predictions on the single photon-beam asymmetry (Σ) as well as the energy and angular dependence for the cross sections of this reaction.

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I. INTRODUCTION

Strange-meson photoproduction is one of the most practical and useful experimental and theoretical methods to investigate the strangeness production processes in hadron physics. In this article, we report our recent study for $K^*\Lambda(1116)$ photoproduction, which employs the effective Lagrangian method in the tree-level Born approximation. In previous studies, it was noted that the production rate of theoretical calculations is insufficient to reproduce the experimental data for this process in the threshold energy region [1–5]. To explain the discrepancies between theory and experiments, we investigate the role of nucleon resonances whose masses are in this energy region. For this purpose, we consider the $D_{13}(2080)$ and the $D_{15}(2200)$ nucleon resonances on top of the relevant nucleon Born terms. We use the resonance parameters extracted from experimental information of the PDG [6] or the theoretical predictions of the relativistic quark-model of Refs. [7, 8]. Our numerical results show that the role of the $D_{13}(2080)$ is essential to reproduce the experimental data for the cross sections of $K^*\Lambda(1116)$ photoproduction, whereas the $D_{15}(2200)$ contribution is rather small. This implies that the nucleon resonance contribution is crucial in the production mechanisms of $K^*\Lambda$ photoproduction near the threshold. The present article is organized as follow. In Section 2, we briefly introduce the theoretical framework for resonance contributions. The numerical results are presented in Section 3 with discussions. Section 4 contains a summary and conclusion.

II. THEORETICAL FORMALISMS

For studying the production mechanisms of $K^*\Lambda(1116)$ photoproduction, we consider the Feynman diagrams as depicted in Fig. 1. Referring the details on the theoretical formalism for the nucleon Born terms and the form factor prescription to Refs. [4, 5], we focus on the role of nucleon resonances. Here, we consider the $D_{13}(2080, 3/2^-)$ and the $D_{15}(2200, 5/2^-)$ whose masses are close to the threshold energy of $\gamma N \to K^*\Lambda(1116)$. The effective Lagrangians for the electromagnetic (EM) interactions are

$$\begin{aligned}
\mathcal{L}_{\gamma N D_{13}} &= -\frac{ieh_{1D_{13}}}{2M_N}\bar{N}\gamma_\nu F^{\mu\nu}R_\mu - \frac{eh_{2D_{13}}}{(2M_N)^2}\partial_\nu \bar{N}F^{\mu\nu}R_\mu + \text{h.c.} \\
\mathcal{L}_{\gamma N D_{15}} &= \frac{eh_{1D_{15}}}{(2M_N)^2}\bar{N}\gamma_\nu\gamma_5\partial^\alpha F^{\mu\nu}R_{\mu\alpha} - \frac{ieh_{2D_{15}}}{(2M_N)^3}\partial_\nu\bar{N}\gamma_5\partial^\alpha F^{\mu\nu}R_{\mu\alpha} + \text{h.c.},
\end{aligned} \tag{1}$$

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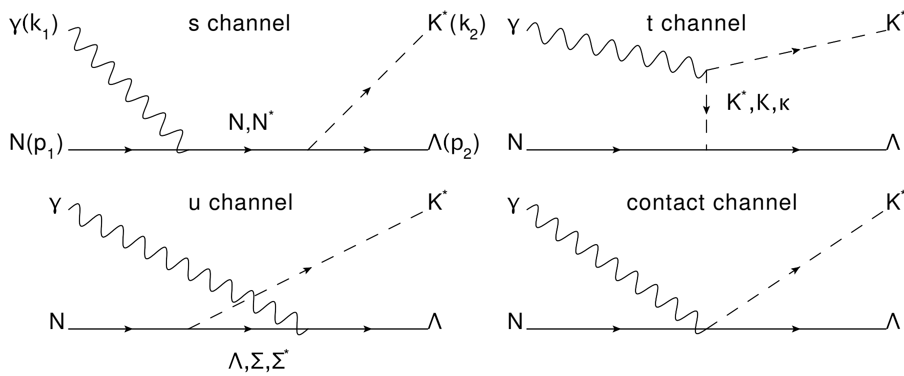

FIG. 1: Relevant Feynman diagrams for $K^*\Lambda(1116)$ photoproduction at tree level. All the momenta for the involved particles are also defined.

where R stands for the resonance field with given spin and parity. The strengths of the couplings in Eq. (1) can be determined from the experimental values for the corresponding helicity amplitudes [6] or quark model [7], which gives $h_{1D_{13}} = 0.829$,$h_{2D_{13}} = -0.845$, $h_{1D_{15}} = 0.346$, and $h_{2D_{15}} = 0.031$.

The effective Lagrangians for the relevant interactions of the resonances with the $K^*\Lambda$ channel are

$$\begin{aligned}\mathcal{L}_{K^*D_{13}\Lambda} &= -\frac{i}{2M_N}\left[g_{1D_{13}}\bar{\Lambda}\gamma_\nu - \frac{ig_{2D_{13}}}{2M_N}\partial_\nu\bar{\Lambda} + \frac{ig_{3D_{13}}}{2M_N}\bar{\Lambda}\partial_\nu\right]K^{*\mu\nu}R_\mu + \text{h.c.}\\ \mathcal{L}_{K^*D_{15}\Lambda} &= \frac{1}{(2M_N)^2}\left[g_{1D_{15}}\bar{\Lambda}\gamma_\nu\gamma_5\partial^\alpha - \frac{ig_{2D_{15}}}{2M_N}\partial_\nu\bar{\Lambda}\gamma_5\partial^\alpha + \frac{ig_{3D_{15}}}{2M_N}\bar{\Lambda}\gamma_5\partial^\alpha\partial_\nu\right]K^{*\mu\nu}R_{\mu\alpha} + \text{h.c.}.\end{aligned} \tag{2}$$

The strong coupling constants in Eq. (2) are unknown and, to fix these parameters, we use the theoretical estimations in the relativistic quark model [8] on the partial decay widths of the resonances,

$$\Gamma_{R\to K^*\Lambda} = \sum_\ell |G(\ell)|^2\,, \tag{3}$$

where the values for $G(\ell)$ are given in Refs. [8]. The partial decay width $\Gamma_{R\to K^*\Lambda}$ can be calculated from the interaction Lagrangians in Eq. (2) and we can estimate the strong coupling constants of Eq. (2). Since we focus on the role of nucleon resonances near the threshold, we take into account only the lowest partial-wave contributions. Hence, we neglect the $g_{(2,3)R}$ terms in Eq. (2) and employ only the contributions of the lowest orbital angular momentum in $G(\ell)$. With this simplified model, we present the numerical results using $|g_{1D_{13}}| = 1.59$ and $|g_{1D_{15}}| = 1.03$. The relative signs of these coupling constants to the other contributions will be examined by comparing with the experimental data on the cross sections. All the other couplings and parameters are the same as in Refs. [4, 5].

III. NUMERICAL RESULTS

In this Section, we present the numerical results for $K^*\Lambda(1116)$ photoproduction off the proton target. In the left panel of Fig. 2, our results for the differential cross sections $d\sigma/d\cos\theta$ for this reaction are shown with respect to $\cos\theta$, where θ denotes the scattering angle between the incident photon beam and outgoing K^* in the center-of-mass frame. Here, we only present the results for $E_\gamma = 2.35$ GeV. This shows that the role of the resonances is crucial to reproduce the recent experimental data from the CLAS Collaboration at TJNAF [2]. Furthermore, we found that the D_{15} contribution is minor in comparison to that of the D_{13}. Note that our results underestimate the data in the backward scattering region, i.e. $\cos\theta \approx -1$. We ascribe this discrepancy to underestimating the role of the u-channel hyperon-pole contributions. In the present study, we do not consider u-channel hyperon resonances apart from the Λ, the Σ, and the Σ^*. Varying the photon beam energy, we verified that the experimental data for the differential cross sections in the range of $E_\gamma = (2.15 \sim 2.65)$ GeV are qualitatively well reproduced in this model. The details will be reported elsewhere.

Shown in the right panel of Fig. 2 are the results for the total cross sections with and without the resonance contributions. The experimental data are extracted from those of the differential cross sections for $E_\gamma = (2.05 \sim 2.65)$ GeV in Ref. [2], and we only quote the central values. Here, the nucleon Born term contribution is given by the dashed curve, while the D_{13} and D_{15} contributions are drawn in the dotted and the dot-dashed ones, respectively.

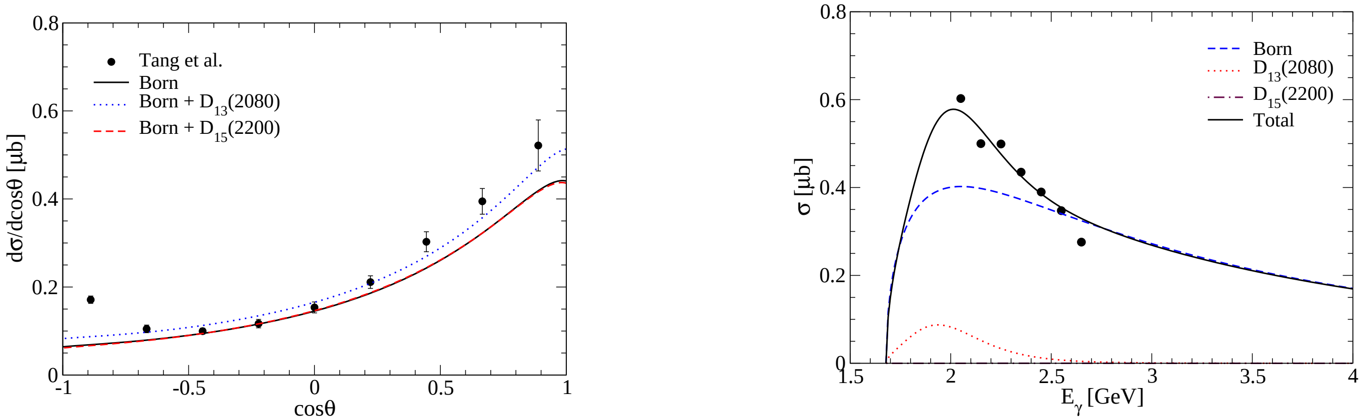

FIG. 2: (Color online) Differential cross sections at $E_\gamma = 2.35$ GeV as a function of $\cos\theta$ (left) and the total cross sections as a function of E_γ (right) with and without the nucleon resonances. The experimental data are taken from Ref. [2].

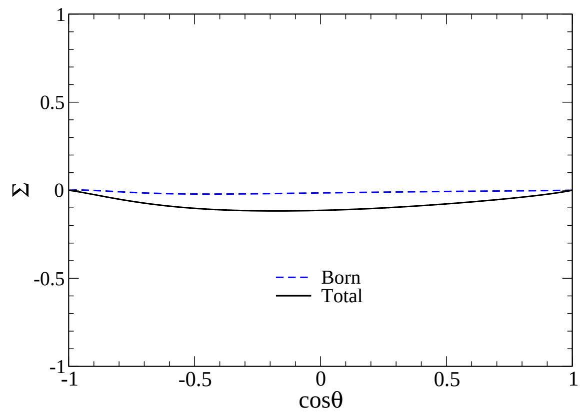

FIG. 3: (Color online) Photon-beam asymmetry Σ with and without the nucleon-resonance contributions as functions of $\cos\theta$ at $E_\gamma = 2.35$ GeV.

This again shows that the D_{15} contribution is negligible, and the production rate in the energy of $E_\gamma \leq 2.5$ GeV is largely dominated by the D_{13} contribution. The enhancement of cross sections in this energy region can not be explained in the simple Born-term calculations in Refs. [4, 5, 10]. We thus conclude that the resonance contribution, in particular the D_{13} contribution, is crucial in understanding the mechanism of the $K^*\Lambda(1116)$ photoproduction.

Finally, we compute a single-polarization quantity, i.e. the photon-beam asymmetry, defined as

$$\Sigma = \frac{d\sigma_\parallel - d\sigma_\perp}{d\sigma_\parallel + d\sigma_\perp}, \tag{4}$$

where the subscripts $\perp$ and $\parallel$ stand for the photon-beam polarization being perpendicular and parallel, respectively, to the reaction plane. In Fig. 3, we show the result for Σ at $E_\gamma = 2.35$ GeV. This shows that Σ is almost zero without nucleon resonances, and the inclusion of the resonance contributions, which are dominated by the D_{13}, can give non-vanishing asymmetry in the region of $\cos\theta \approx (-0.15 \sim 0.5)$, which indicates that the magnetic-transition contribution becomes larger.

IV. SUMMARY AND CONCLUSION

In this work, we investigated the mechanism of the $K^*\Lambda$ photoproduction based on the effective Lagrangian method at the tree-level Born approximation with nucleon resonances. Our results are obtained with the parameters extracted

from presently available experimental and theoretical information for the D_{13} and D_{15} resonances. We found that the $D_{13}(2080)$ resonance contribution is important and has a crucial role to bring the theoretical results close to the experimental data, in particular, near the threshold region, while the D_{15} contribution is negligible. More detailed analyses with the results on various physical observables are under progress and will be reported elsewhere.

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